Design Guide: TIDA-00848

Single-chip Heat Cost Allocator Reference Design with Segment LCD Control Using GPIO Pins

Description

Segment LCD displays are very popular in ultra-low power metering and submetering applications such as heat cost allocators, water, and heat meters and are typically controlled by a dedicated on-chip LCD controller module in the MCU. This design shows an alternative, TI patented, design that can be used with any TI MCU without such module. Using a resistor network and GPIO control software, the LCD drive functionality has been implemented on the sensor controller engine inside the CC1312R wireless MCU to achieve a power consumption of 7.3µA (no LCD attached). To achieve the lowest power consumption in heat cost allocators compliant with the EN 834 norm, the LCD can be activated by the user through a capacitive touch or a push button event.

Resources

TIDA-00848	Design Folder
CC1312R	Product Folder
TMP63	Product Folder
TLV2333	Product Folder
TIDA-00848	Tools Folder

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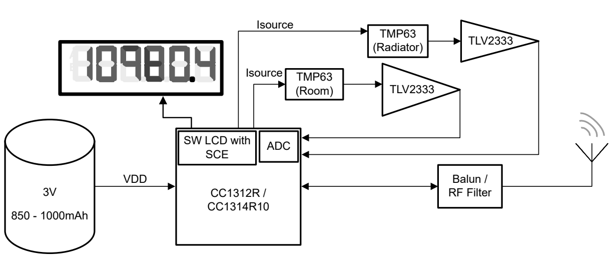
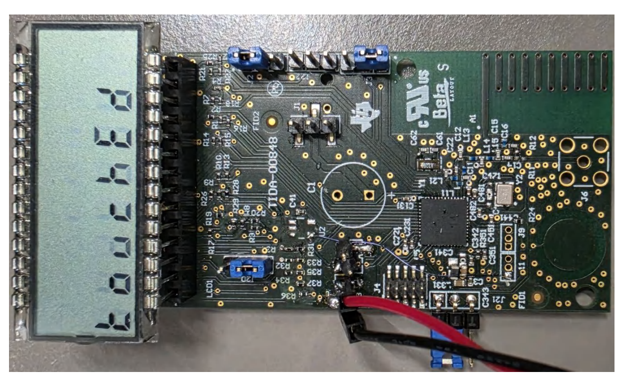
Features

- CC1312 SimpleLink™ wireless MCU controls segment LCD through GPIOs (TI patented design for TI MCUs)
- Only four COM, two control, and 21 segment lines (27 I/Os total) needed to drive 84 LCD segments (4-MUX, 1/3-Biasing)
- Sensor controller peripheral reads out two TMP63 sensors periodically and checks for CapTouch events and implements an IrDA communication port
- Two-layer PCB with HCA form factor using a 96-Segment LCD (4-MUX) and cap touch area for LCD on/off
- Average current: 835nA at 3.6V (LCD Off); 7.3µA for SCE only, 11.9µA at 3.3V (28 segments on with BTL002 4-MUX LCD)

Applications

- Heat Cost Allocator
- Water Meter
- Thermal (Heat / Cold) Meter





1 Key System Specifications

The CC1312 Wireless MCU operates from 1.8 to 3.8V (4.1V is the absolute maximum value allowed) and defines the supply voltage range for the TIDA-00848. This is a great fit for primary battery chemistries, such as LiSoCl2 with 3.6V or LiMnO2 with 3.0V nominal voltage.

The TMP63, a silicon-based linear thermistor with a positive temperature coefficient (PTC), operates from 0 to 5.5V with a 100kΩ nominal resistance at 25°C (R25) and +-1 % maximum (0°C to 70°C). The device has a 0.2% typical TCR tolerance across temperature range and a fast thermal response of 0.6s in the standard 0402 DEC package.

The OPA2333, dual low-noise, RRIO, CMOS Operation amplifier for Cost-Sensitive systems operates from 1.8V to 5.5V if only a positive supply voltage is used.

Table 1-1. Key System Specifications

FEATURES	DESCRIPTION
TI wireless MCU	CC1312R, CC1312R7, CC1314R10
LCD Frame rate	Adjustable through software (RTOS ticks based)
LCD mux ratio	4MUX, 1/3 bias
# of GPIOs (4 COM + 2 AUX + N SEG lines)	Max. 30 (CC1312R / CC1312R7) Max. 46 (CC1314R10)
Operating temperature range (°C)	-40 to 105°C (CC1312R, CC1312R7 and CC1314R10) -40 to 150°C (TMP63) 4-MUX LCD unit (see datasheet)
Current consumption	11.9µA at 3V3 (28 SEGs on)
Operating Voltage	1.8 - 3.8V
Operating system (SW example)	TI-RTOS or FreeRTOS
LCD waveform generation	Sensor Controller Engine (16-bit MCU module)
Battery (primary LiIon-cell)	3.0V LiMnO2 3.6V LiSoCl2

2 System Description

Heat Cost Allocator (HCA) devices are used to measure the consumed heating cost in buildings with a central heating source (like heated water) and multiple radiator units in each premises. HCAs work in conjunction with a heat meter, which measures physical energy in kilowatt-hours (kWh): each HCA records relative *units* of heat consumption for the radiator body, where the HCA gets attached to, to determine each tenant's fair share of the total heating cost bill. As per the European Energy Efficiency Directive (EED), charging must be based on actual usage rather than the floor area of the apartment. Heat cost allocators (HCAs) start registering (measuring) at temperatures of 20°C or above.

HCAs integrate several sub-systems:

- *temperature sensing* (single- or mainly dual-sensor for Room and Radiator)
- *RF (Radio Frequency)* 868MHz with wM-Bus with C-mode (S- and T-modes are being phased out)
- *Segment LCD* for displaying the consumed relative *units*
- *Optical (IrDA*) single or dual LED used to read out data and configure the HCA device in the field, also used during manufacturing of the HCA device
- *Battery* (primary cell with about 1000mAh (typ.) capacity for > 12 years lifetime, consisting of 10-11 years operation + shelve time + several months operating margin)
- *Processing* (ultra-low power MCU core which processes the temperature sensor data a few times per minute using an algorithm to convert temperature differences and time into consumption units.
- *Security and Anti-Tamper* includes physical seals and electronic anti-tampering sensors or other means that detect and log any attempts to or removal of the device from the radiator

Note

This TI patented design for driving segmented LCD displays with Multiplexer Resistor network can only be used *free of charge* in combination with any wired or wireless MCU products by Texas Instruments Inc., such as MSPM0+, MSPM33, C2000™, CC13xx, CC26xx and CC27xx families and others.

The TIDA-00848 represents a single-chip reference design for wM-Bus at 868MHz enabled HCAs, meeting these EN 834 requirements:

- Two cost-effective TMP63 linear thermistor temperature sensors to replace commonly used NTCs for room and radiator sensors
- CC1312R Wireless SoC for wM-Bus at 868MHz RF subsystem with C-mode, and has proven support for mioty (tm) mode.

TIDA-00848 drives the segment LCD display through a dedicated external resistor network (see Section 8.1) and special software, provided as an open-source code example. The CC1312R's sensor controller peripheral periodically reads the voltage of the two TMP63 sensors, and converts the values into temperature units; otherwise, the TMP63 sensors are powered down using GPIO pins. In parallel, the sensor controller is programmed to check periodically (for example, every second) for a PCB touch event. If such touch event is detected, the LCD functionality is enabled and the LCD will from now on be enabled until a programmable timeout occurs, with a maximum of 84 segments on (visible). The LCD support functionality is integrated into TI's Sensor Controller Studio tool and supports 4-MUX LCD displays and can be utilized to any application with a TI Wireless MCU with a Sensor Controller Engine module.

2.1 CC1312R SimpleLink 32-bit Arm Cortex-M4F Sub-1 GHz wireless MCU with 352kB Flashes

The CC1312 Wireless MCU has an ARM® Cortex®-M4F core for application development (see Figure 2-1).

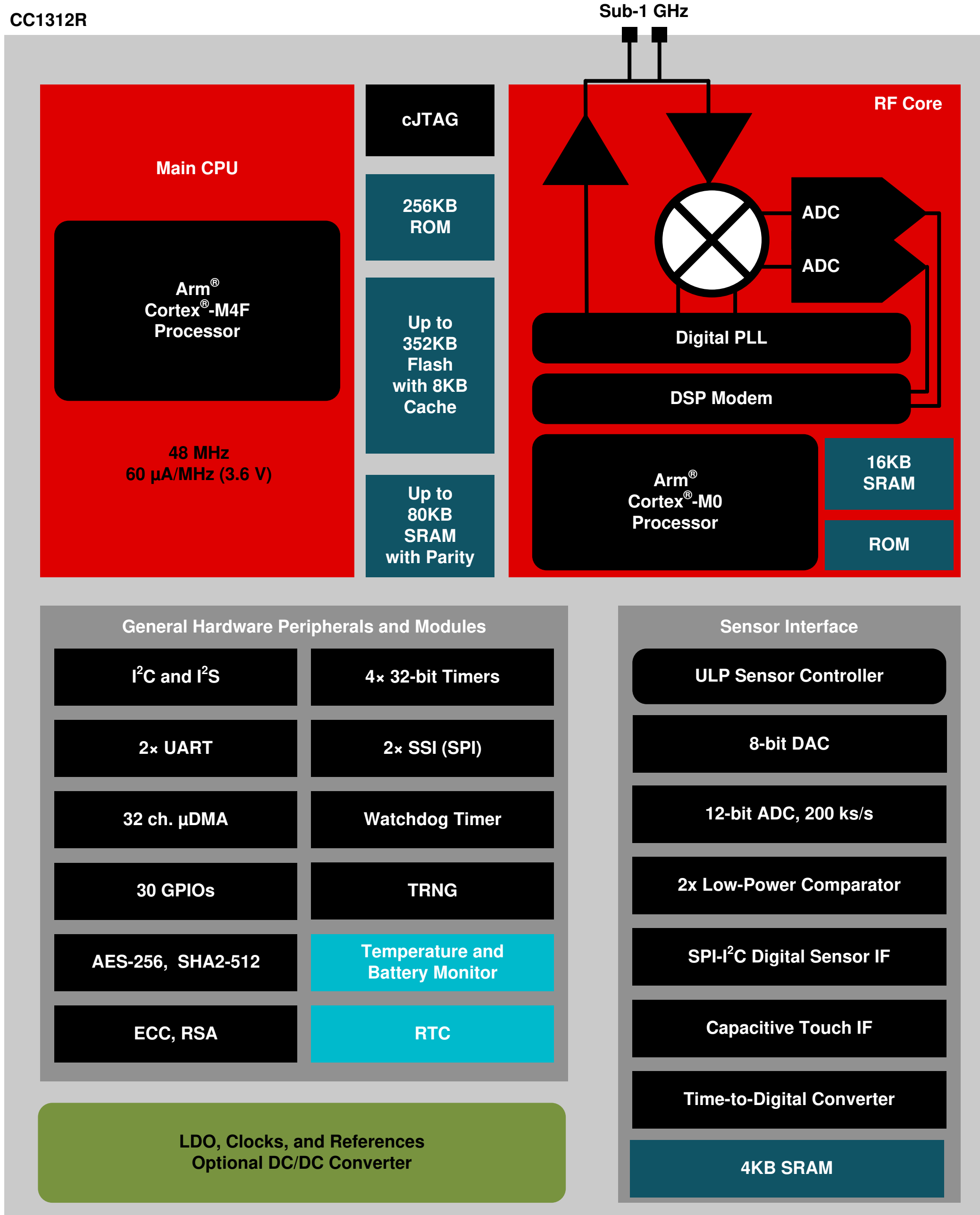


Figure 2-1. CC1312 Block Diagram

CC1312R provides a high-performance, low-cost platform that meets the system requirements of minimal memory implementation and low-power consumption while delivering outstanding computational performance and exceptional system response to interrupts. The ARM Cortex-M4F core runs with up to 48MHz, and there is also 352KB of in-system programmable Flash, 8KB of SRAM for cache (or as general-purpose RAM), and 80KB of ultralow leakage SRAM with parity in the device. The Sensor Controller Engine (SCE) has been optimized for ultralow power and can run autonomously from the rest of the system at 24MHz or 2MHz low-power mode, using only 0.4mA + 8.2µA/MHz.

The SCE, being a proprietary power-optimized 16-bit CPU, which can read and monitor sensors or perform other tasks autonomously; thereby significantly reducing power consumption and offloading the main Cortex-M4F

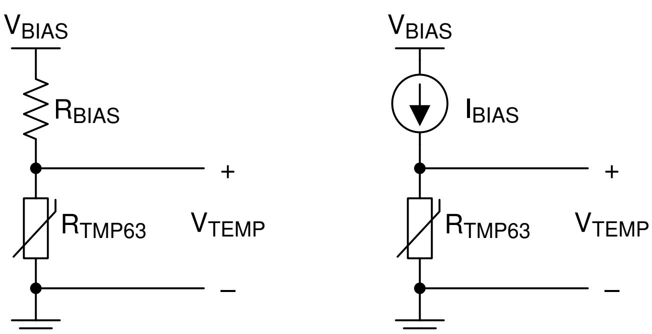
CPU. The SCE has a 16-bit architecture, and has its dedicated 4KB of ultralow leakage SRAM for code and data. The CC1312 standby current is 0.85µA (with RTC on, 80KB RAM and CPU retention). The SCE seamlessly interfaces to and reads the TMP63 sensors and the capacitive touch PCB area to deliver outstanding low-power consumption with very good precision, suited for HCAs as per EN 834.

The Sensor Controller Engine or SCE, contains circuitry that can be selectively enabled in standby mode and supports a 2MHz operating mode for lowest power use cases, in addition to the 24MHZ mode, which is suited for higher compute and very precise timing.

One key CC1312 peripheral is the SAR ADC module, a 12-bit 200k samples per second ADC with eight inputs and a built-in voltage reference. The analog modules connect to up to eight different GPIOs. Each CC1312R device comes with two calibrations values at room temperature for the ADC12: one for gain and one for offset, being written into a dedicated flash area by TI during device manufacturing.

2.2 TMP63 ±1% 100kΩ Linear Thermistor in 0402 Package

Linear thermistors offer linearity and consistent sensitivity across temperature to enable simple and accurate methods for temperature conversion. Low power consumption and a small thermal mass minimize the impact of self-heating. With built-in failsafe behavior at high temperatures and powerful immunity to environmental variation, these devices are designed for a long lifetime of high performance. The small size of the TMP6 series also allows for close placement to heat sources and quick response times. Take advantage of benefits over NTC thermistors such as no extra linearization circuitry, minimized or no calibration altogether, less resistance tolerance variation, and simplified conversion methods to save time and memory in the MCU.



$$V_{TEMP} = \frac{V_{BIAS} \times R_{TMP63}}{R_{BIAS} + R_{TMP63}} \qquad V_{TEMP} = I_{BIAS} \times R_{TMP63}$$

Figure 2-2. TMP63 # Typical Implementation

The two TMP63 are directly excited by the programmable current source module inside the SCE, enabling very small form factor, ultra low-cost temperature measurement solution.

The TMP63 silicon linear thermistor has a linear positive temperature coefficient (PTC) that results in a uniform and consistent temperature coefficient resistance (TCR) across a wide operating temperature range. TI uses a special silicon process where the doping level and active region areas devices control the key characteristics (the temperature coefficient resistance (TCR) and nominal resistance (R25)) . The device has an active area and a substrate due to the polarized terminals. Connect the positive terminal to the highest voltage potential. Connect the negative terminal to the lowest voltage potential. Unlike an NTC, which is a purely resistive device, the TMP63 resistance is affected by the current across the device and the resistance changes when the temperature changes.

The TMP63 is a cost-effective, small size replacement precision NTC and PTC thermistors with accuracy specified as:

- ±1% maximum (0 °C to 70 °C)
- 0.3% typical long term sensor drift

TMP63 delivers multiple benefits over NTC thermistors such as no extra linearization circuitry, minimized calibration, less resistance tolerance variation, and simplified conversion methods to save time and memory in the microcontroller.

The TMP63 is currently available in a 0402 footprint-compatible X1SON package, which makes it an ideal solution for sub-metering applications such as HCAs.

TLV2333 Dual, 350-kHz, Low-Noise, RRIO, CMOS Operational Amplifier for Cost-Sensitive Systems

The TLVx333 series of CMOS operational amplifiers offer precision performance at a competitive price. These devices are members of the zero-drift family of amplifiers that uses a proprietary auto calibration technique to simultaneously provide low offset voltage (15μV, max) and near-zero drift over time and temperature at only 28μA (max) of quiescent current. The TLVx333 family features rail to-rail input and output in addition to near-flat 1/f noise, making this amplifier ideal for many applications and much easier to design into a system. These devices are optimized for low-voltage operation as low as 1.8V (±0.9V) and up to 5.5V (±2.75V). The TLV333 (single version) is available in the SC70 5, SOT23-5, and SOIC-8 packages. The TLV2333 (dual version) is offered in VSSOP-8 and SOIC-8 packages. The TLV4333 is offered in the standard SOIC-14 and TSSOP-14 packages. All versions are specified for operation from–40°C to +125°C.

3 System Design Theory

HCAs are expected to start measuring at temperature of 20°C with the maximum supported temperature is usually 90°C to 95°C.

For RF-enabled systems, an MCU + RF transmitter (or transceiver) is required, hence single-chip designs such as TI's CC1312R SimpleLink Wireless MCU are preferred, due to minimal PCB area, the integration of applicationMCU and RF sub-system and ease of use. As the CC1312R has no integrated LCD controller hardware module, the TI patented solution for driving LCD thru GPIOs presented here, has been developed and tested.

3.1 CC1312R as Main Application MCU

For measuring temperature, the current source and the ADC12 module in CC1312R are used. The CC1312's 12-bit ADC has two references: a scaled input for a scaled reference of 4.3V or relative reference, which is nominally the VDDS supply voltage of CC1312R. Note that with LiMnO2 batteries this voltage drops over time and often the battery end-of-life voltage is set at around 2 or 2.1V.

In this TI Design, the sensor controller periodically enables the integrated programmable current source with maximum current of 20uA, implementing a current biasing scheme for both TMP63 devices. The current, driving the room and the radiator sensors must be the same value, routed to a different analog pin, to maintain a ratio-metric measurement.

The voltage drop generated by each TMP63 device with using exactly the same excitation current from the SCE module is amplified in a single-stage amplifier circuit to increase dynamic range, which is necessary at higher temperatures, as seen by the Radiator sensor. The implemented design achieves close to 4× higher resolution for the range of 20° to 90°C (including additional 1.5ºC are added margin on both upper and lower end of this range).

The amplified signal for each TMP63 sensor is fed into the ADC12 on-chip module and converted by firmware into temperature values.

The main application runs under TI RTOS on CC1312R, as TI RTOS enables exact scheduling of the temperature measurements, the PCB touch detection and all other application code.

3.2 TMP63 Linear Thermistors With TLV2333 Amplifier

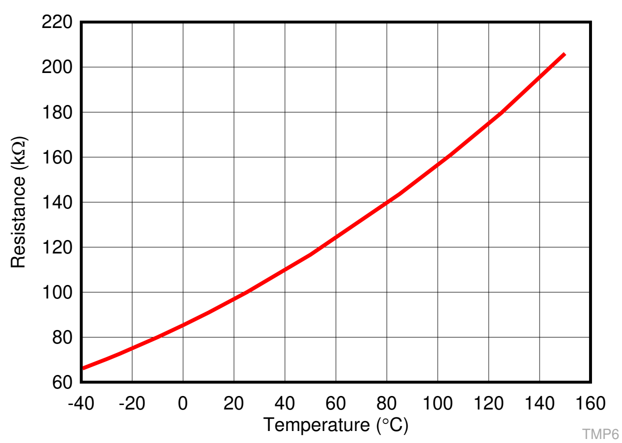


Figure 3-1. TMP63 Typical Resistance versus Ambient Temperature

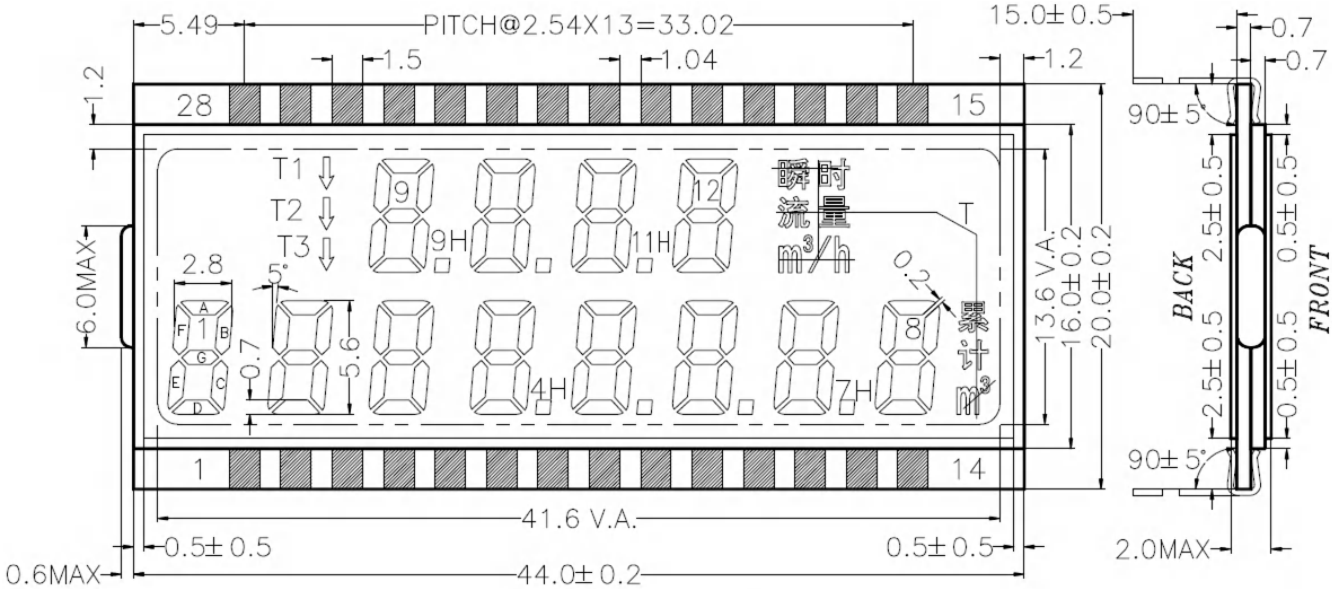
The TMP63 resistance plot across the temperature range is documented in the device’s data sheet (TMP63). The Thermistor Design Tool (an Excel based tool, provided on TI.com), when set for TMP6331DYAT with 10uA Biasing current and using 12-bit ADC with Vreference of 2.1V shows a typical Rvalue = 95458Ω at 20ºC and Rvalue= 144779Ω at 90ºC. For the extended range of 18 to 95ºC temperature difference represents only 54,625Ω × 10μA = 0.546V. As the ADC12 full range is 2.1V for a minimum supply=voltage of 2.1V, the first TLV2333 amplifier implements a near 4× gain stage, which extends the voltage range to 0.051V to 2.05V, providing close to 4× better resolution.

The room temperature can be measured in two ways: assuming 20 to 40ºC input range, the biasing current can be set between 10 to 15uA without amplification stage. If higher resolution is required, then a single-stage amplifier circuit, similar to the radiator sensor has been designed and simulated, delivering close to 12× higher resolution range: 0.238V to 2.07V, utilizing the second amplifier unit in TLV2333.

3.3 4-MUX 1/3 Biasing Seven-Segment LCD With 84 Segments

The LCD BTL002 with 96 segments and 4-MUX capability was chosen due to the small physical dimensions and low-power consumption.

The specification of the LCD is given in Figure 3-2:



PIN	1	2	3	4	5	6	7	8	9	10	11	12	13	14
COM1	1A	1F	2A	2F	3A	3F	4A	4F	5A	5F	6A	6F	7A	7F
COM2	1B	1G	2B	2G	3B	3G	4B	4G	5B	5G	6B	6G	7B	7G
COM3	1C	1E	2C	2E	3C	3E	4C	4E	5C	5E	6C	6E	7C	7E
COM4	T1	1D	T2	2D	T3	3D	4H	4D	5H	5D	6H	6D	7H	7D

PIN	15	16	17	18	19	20	21	22	23	24	25	26	27	28
COM1	8A	8F	9A	9F	10A	10F	11A	11F	12A	12F	COM1	--	--	--
COM2	8B	8G	9B	9G	10B	10G	11B	11G	12B	12G	--	COM2	--	--
COM3	8C	8E	9C	9E	10C	10E	11C	11E	12C	12E	--	--	COM3	--
COM4	T	8D	9H	9D	10H	10D	11H	11D	--	12D	--	--	--	COM4

Figure 3-2. BTL002 Specification (96-Segment LCD)

3.4 Segment LCD Control with GPIOs Design Description (TI Patented Design)

Figure 3-3 shows the TI patented circuit for generating all four COM signals and one of the SEG signals. Each SEG line has a GPIO pin and is connected to four different LCD segments (if 4 MUX LCD is used), as well as to the SEG_BASE_COMMON signal over a separate resistor R_{seg}. Each of the four LCD segments connected to one SEG line is connected to a different COM line.

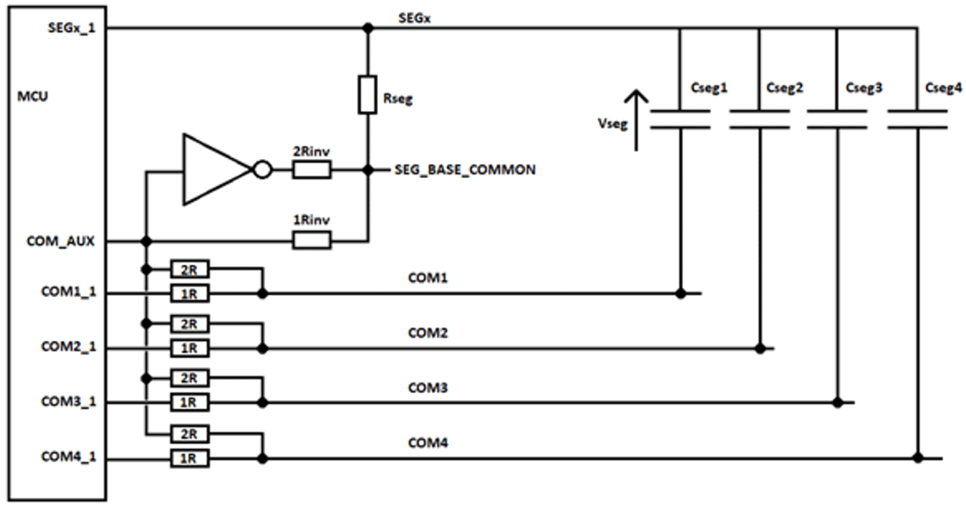


Figure 3-3. TI Patented MUX LCD Signal Generation, 4 LCD Segments Shown as Capacitance Cseg1 to Cseg4

Resistors 1R and 2R in image above mean that the value of 2R is twice larger than 1R, same applies for the $2R_{inv}$ and $1R_{inv}$ resistors around the optional external inverter device.

All GPIOs used for the generation of the COM signals as well as the BASE_PWM and BASE_PWM_N signals are configured as outputs. The signals of the COM outputs are shown below. To generate the SEG_BASE_COMMON signal, a separate GPIO as BASE_PWM_N can be used instead of the inverter. The biasing value of any LCD defines how many intermediate voltage levels the LCD supply voltage (V_{LCD}) is divided into. For example, the 1/3 biasing of the BTL002 display means there are four different voltage levels: $0V_{LCD}$; $1/3V_{LCD}$; $2/3V_{LCD}$; and $3/3V_{LCD}$.

3.5 Generating Square LCD Waveforms Through GPIOs (TI Patented Design)

Problem: How to generate a square wave signal, toggling between $2/3V_{LCD}$ and $1/3V_{LCD}$ by only using logic signals, which toggle between V_{LCD} and GND?

The TI patented design provides a way to generate the intermediate LCD voltage levels of $1/3V_{LCD}$ and $2/3V_{LCD}$ by using a resistive network, an inverter and the superposition of the COM signals with an auxiliary clock signal, BASE_PWM. The second variant of the TI patented design defines that the inverter function is replaced thru additional GPIO signal, called BASE_PWM_N.

Contrary to a PWM-based GPIO approach, existing today, the number of external components of the TI design is less. Only resistors and the optional single inverter are required. On the firmware side, no high-speed complex signals are required just a simple timer tick-based switching of IOs at a 8× rate of the LCD frame update frequency. This reduces the necessary resources on the MCU and thus also the current consumption significantly, compared to a PWM-based GPIO LCD design.

3.5.1 COM Lines Generation

The square waveforms are generated using one additional signal, called BASE_PWM, and the inverted version, named BASE_PWM_N, with the help of resistor divider networks, see R30-R38 in TIDA-00848 schematic, with 1MΩ and 2MΩ, respectively. In addition, the R28 and R29 resistor divider again uses this 1/3-to-2/3 ratio, the resistor values are also 1MΩ and 2MΩ. The current flowing through the SEG_BASE_COMMON is, at worst, shared by the 21 segment lines, when all 84 LCD segments are on.

While the operation of the U2 SN74AHC1G04 inverter has been tested successfully, a significant drawback of continuous extra current flowing through the resistor network R28 and R29 was identified. Thus, the final implementation (optimized for lower power consumption) removed the inverter and repurposed the DIO_27 pin of the CC1312 as the BASE_PWM_N signal, which is simply the inverted version of the BASE_PWM. By setting the DIO_27 or BASE_PWM_N to output low state while the LCD is inactive, the current through R28 and R29 is eliminated.

The COM and Segment electrodes in any segmented LCD form at their intersection a capacitor, with the liquid crystal as dielectric matter in between them. In a 4-MUX display, one LCD segment pin is internally connected to 4 (or fewer) segments: pin segment 1 (S1) of the BTL002 connects to the 1A, 1B, 1C, and T1 segments on the display—see the left column for Pin1 in Figure 3-2. Note that and each of these segments connects to a different COM plane (COM line) to enable a time multiplexing control of each segment.

The required voltage to drive a segment LCD device has to be DC free in respect to 0 V_{LCD}, thus after driving the common plane (COM signal) a second phase is needed with the reversed polarity, see *Technical Information and Application Notes*.

Thus for the BTL002 display, there must be 4 COM × 2 = 8 sub-divisions in every single frame sent to the LCD. This is shown in for the COM0 line with the f_{frame} period; the frame rate is commonly selected between 25 frames per second (fps) for flicker-free LCD viewing and maximum of 60Hz to keep current consumption at a reasonable value.

In the TIDA-00848 source code project, the following definitions have been made:

- Two BASE_PWM/BASE_PWM_N and four COM lines to generate the proper waveforms with minimum MCU effort
- Eight subphases (one for driving the COM plane and segments; the next is a reversed polarity for DC free control of the LCD)
- Segment lines need to be dynamically tri-stated, or set to output HIGH or LOW for each subphase

All these functions have been implemented in the LCD resource for the SCE module, which is running at 2MHz for lowest power consumption.

3.5.1.1 Segment Lines

In TIDA-00848, the segment lines between CC1312 and BTL002 correspond to DIO_1 through DIO_21, the COM pins are DIO22 through DIO25, BASE_PWM and BASE_PWM_N are DIO 26 and DIO27 respectively. For demonstrating the LCD functionality, DIO_27 is assigned to the BASE_PWM_N and is not used by the TMP63 sensor.

3.5.2 Segment Line Generation

To generate the appropriate segment line waveforms for the LCD one has to set the corresponding MCU GPIO pins either in tri-state (for segment off), or in the two output states HIGH/LOW, in case of segment on. The full amplitude is the result of the differential voltage between segment and COM lines at the LCD pins.

To enable the generation of these segment waveforms, a common support signal, named SEG_BASE_COM signal has been defined. This SEG_BASE_COM signal delivers a simple pulse sequence with the same eight subphase timing and switching between the values of 1/3 and 2/3 V_{LCD}.

Detailed Analysis of Timings, DC Offset and Voltage Levels

Andreas Lechner's Bachelor thesis has a detailed analysis of the influence of various parameters on the voltage $V_{\mathbf{Seg}}$ applied to an LCD segment. The RMS of $V_{\mathbf{Seg}}$, called $V_{\mathbf{RMS}}$, decides if a segment is visible or not. Additionally, the LCD segments are very susceptible against DC voltages. Therefore, $V_{\mathbf{Seg}}$ must not have a DC offset.

DC offset

The LCD segments must not be exposed to DC voltages for an excessive amount of time. Otherwise, a chemical process starts to decompose the liquid crystals over time, eventually resulting in a non-functional segment. An exact time after a DC voltage damages an LCD cell cannot be defined. A few minutes do not instantly destroy the cell but reduce the lifetime. Since the display works for many years, DC offsets can be avoided; for most LCD displays +/- 50mV is specified as the maximum allowed DC voltage.

Therefore, the voltage V**seg** connected to the display must not contain a DC offset. This is verified if both COM and SEG signals are DC free in relation to ½ $V_{\mathbf{LCD}}$. This is only true if all signal GPIOs are switched simultaneously and the voltage levels are accurate, therefore LCD frame timings are important. In the following part potential sources of a DC offset are analyzed.

Effect of Resistor Tolerances on DC Offsets of COM and SEG Signals

The influence of resistor tolerances on the DC Offset in relation to ½$V_{\mathbf{LCD}}$ of a COM signal is analyzed. A constant value of T**sub-frame** has been assumed as the basis of all the following equations. The final result is that the resistor tolerance has no impact on $V_{\mathbf{RMS}}$ of the COM signal and thus no DC offset in relation to ½$V_{\mathbf{LCD}}$ is caused ***if*** T**sub-frame** remains constant.

Effect of Inconsistent Tsub-frame on the DC Offset

A voltage DC offset can be caused if T**sub-frame** is not constant. The worst case for this offset is, if the timing of the full swing from 0V to $V_{\mathbf{LCD}}$ is delayed. See an example equation for the allowed delay $T_{\mathbf{DelayMax}}$ below.

Parameters: $\mathbf{V_{LCD}}$ = 3.3V

$\mathbf{T_{Sub\text{-}frame}}$ = 4.1667ms (30 Hz frame rate)

$\mathbf{V_{DCOffset}}$ = +/-50mV (maximum DC voltage allowed)

$T_{DelayMax} = \mathbf{V_{DCOffset}} / \mathbf{V_{LCD}} \cdot 2 \cdot \mathbf{T_{Sub\text{-}frame}}$

$T_{DelayMax} = (0.05\ V)/(3.3\ V) \cdot 2 \cdot 4.1667\ ms = 126.2\ \mu s$

This equation shows that a delay in $T_{\mathbf{Sub\text{-}frame}}$ greater than 126.2µs, causes a DC offset greater than 50mV, and therefore harms the LCD specification.

Effect of delay between COM and SEG signals on DC offset

The next point is the effect of a theoretical delay between a COM line and a SEG line on the resulting difference voltage $V_{\mathbf{Seg}}$. Such a delay can occur if not all GPIO pins are switched at the same time, but for example, first all COM GPIOs and second all SEG GPIOs are updated. This point is of theoretical interest, as in reality the Sensor Controller Studio LCD resource sets all 30 GPIOs at the same time within a single command.

This effect is investigated by simulating the LCD signal generation, showing that a timing delay between a COM and a SEG line causes close to zero DC offset, as shown in Figure 3-4. The effect of a 100µs delay between

COM line and segment line on the difference voltage V $_{Seg}$ in a typical setup with 10mV is minimal and thus the LCD his means the display cannot be damaged. However, Figure 3-4 shows also that there is an impact on the RMS of the difference voltage V $_{Seg}$ applied to a single segment. In other words a single segment could stay grey instead of being completely visible or invisible, if there is too much delay. A practical value or a formula for an acceptable delay is hard to estimate, because it is strongly dependent on the used display and resistor network. This must be tested with every setup, but in most cases the impact is marginal.

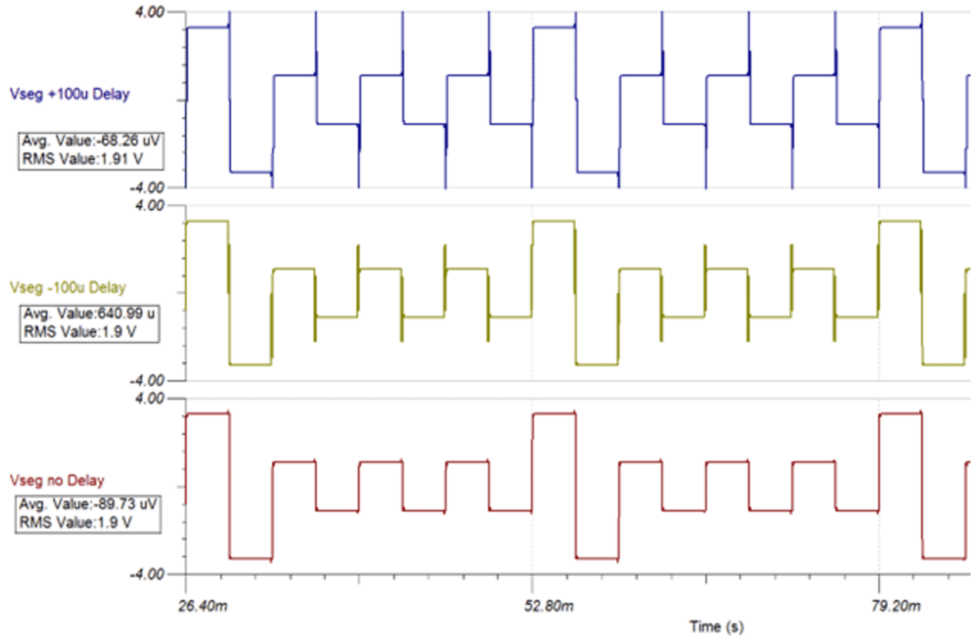


Figure 3-4. *V $_{Seg}$ and the According DC Offset (Avg. Value) and V $_{RMS}$ (RMS Value) with +100µs Delay (Blue), -100µs Delay (Green) and Without Delay (Red)*

The delay causes V $_{RMS}$ to rise to 1.91V in comparison to 1.9V without delay. A slightly higher V $_{RMS}$ is no problem for the LCD functionality, but a reverted delay can also have the opposite effect of lowering V $_{RMS}$, which lowers the contrast of a segment. This effect is not as significant in this simulation as V $_{RMS}$ stays at 1.9V. The most important result of this simulation is that the waveforms with delay between COM and SEG lines have no DC offset, because the anomalies caused by the delay cancel each other out.

3.5.3 Porting the GPIO Software Design to Other 4-MUX, 1/3 Bias LCDs

Obviously, not every application used the BTL002 display, so porting the code to a customer display is necessary. Before doing this, consider the following:

- Get familiar with the LCD Controller Resource, provided in the SCS tool, which can generate complex waveforms at a low update rate on any number of GPIO pins, typically for use with seven-segment LCDs (Liquid Crystal Displays) and similar. This resource has been specifically developed to support TI's patented MUX LCD solution.
- The custom LCD specification drives the assignment of COM and SEG lines.
- Map all four COM lines, up to 24 SEG lines and the two PWM auxiliary signals to DIO1-DIO30 pins of CC1312 and ensure this mapping matches the schematic.

The LCD resource in SCS updates the waveform state (high, low or tri-state) for all used GPIO pins simultaneously, with one Sensor Controller instruction and has been designed for low-power operation at 2MHz, as utilized in this Reference Design. For further details, check the Help Viewer in SCS Tool.

Note that the LCD control is implemented in two parts: besides the SCE resource, an additional code is needed in the main application running on the Cortex-M4F MCU core. The CPU application is responsible for preparing and loading the waveform states into the SCE memory (AUX RAM). There must be one waveform state where all the GPIO pins are tri-stated, that is, the LCD display is not driven. This must be the initial state when starting the Sensor Controller task, and the final state when stopping the Sensor Controller task.

Note

The source code example for the TIDA-00848 is based on the TI RTOS operating system and has been developed to show the software GPIO functionality only. No exact timings have been tested and the correctness of the timings used is not implied.

The user is responsible for maintaining that the LCD control in the application delivers the correct waveform timing and a DC-free voltage for the LCD, especially when other tasks are running on the SCE module.

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4 Block Diagram

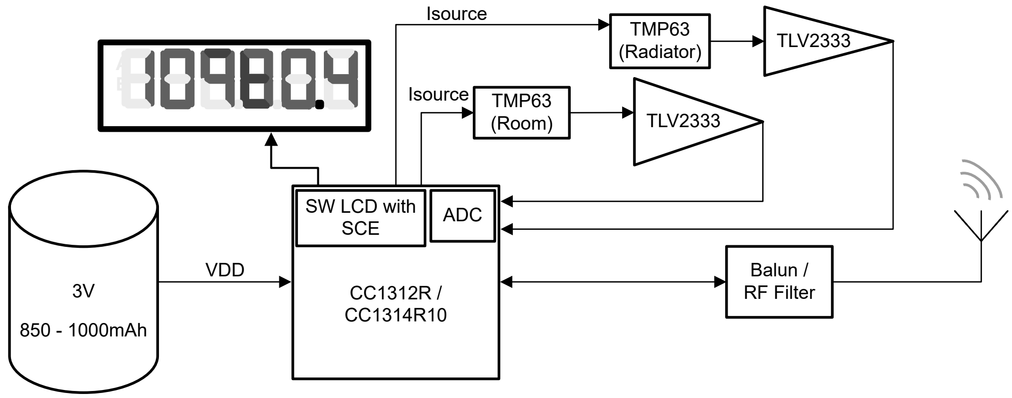

Figure 4-1. Block Diagram of TIDA-00848

The TIDA-00848 Block diagram in shows the two TMP63 and the two OPA units inside one TLV2333 used for the HCA differential temperature measurement. This Reference design has just a few components: two 1% accurate 100-kΩ linear thermistor devices TMP63 as temperature sensors, each of the sensors is paired with one operational amplifier inside TLV2333. All other sub-systems are implemented by the CC1312R Wireless MCU device with an on-chip Sensor Controller Engine and the Current source module, the RTC module, the 12-bit ADC, the COMPA, and the 30 GPIO signals.

5 Getting Started Hardware

The TIDA-00848 hardware can be programmed and debugged using the J4 connector, which is a standard 2×5-pin ARM JTAG connector. A 10-pin flat ribbon cable interfaces J4 to various TI LaunchPad EVM that includes the XDS110 Debugger hardware for programming the CC1312R.

When programming the CC1312R, disconnect the jumper J12, which supplies the battery voltage from the battery holder on the back of the PCB. J12 can be also used to connect a multimeter device for measuring the approximate average current. Note that due to the very short peaks of the power supply, dedicated equipment such as Agilent N6781A is required for precise current consumption measurements. Alternatively, the TI FET430 UIF tool with EnergyTrace (tm) functionality has been used to measure the power consumption numbers, documented here.

5.1 TMP63 Circuitry

The TIDA-00848 PCB can accommodate the TMP63 sensors thru an extension flex PCB or similar, as one temperature sensor measures the radiator body (or heater sensor), and the second sensor captures the room temperature (or room sensor). Any HCA device is mounted firmly onto the heater body, and the heater temperature sensor must have thermal (but not electrical) contact with the heater body. In contrast, the room temperature sensor is orientated into the opposite direction to the room or away from the heater body. The two sensors approach used in this TI Design is described in the EN 834 as the *two-sensor measurement method*.

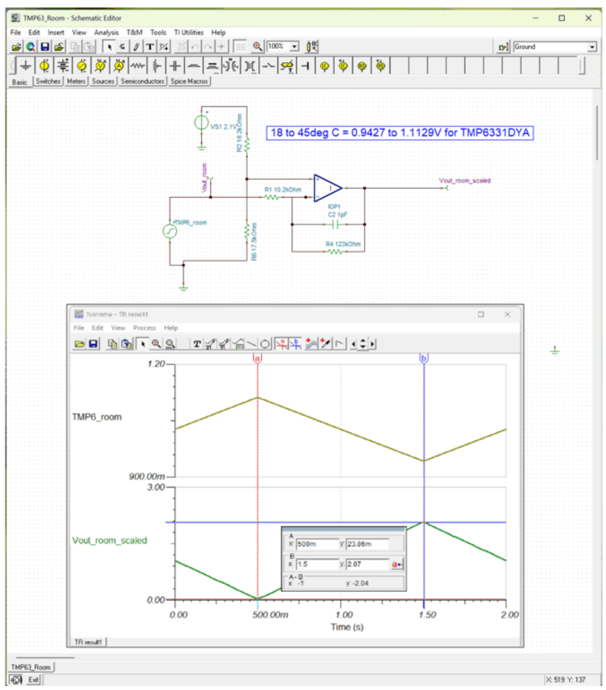

Figure 5-1. TMP63 Room Sensor Circuit With Simulation

For easier evaluation the circuitry with the two TMP63 sensors and the TLV2333 devices can be attached over the two extension headers J9 and J11. Although no hardware design has been done yet, a TINA TI Spice simulation file for each sensor circuit is provided. Both sensor utilize a Current biasing scheme, using the programmable current source module inside the SCE. Two files, one per TMP63 sensor, are included in the Simulation file example at TIDA-00848 folder.

The simulation shows the plot from 18 to 95 °C and 10uA current source excitation thru the CC1312R programmable current source into TMP6331 device. At x = 500m the 18°C minimum is at 2mV voltage level to the ADC12, while at x = 1500m and 95°C the output voltage is 2.1V, when using 2.1V as supply voltage to CC1312R.

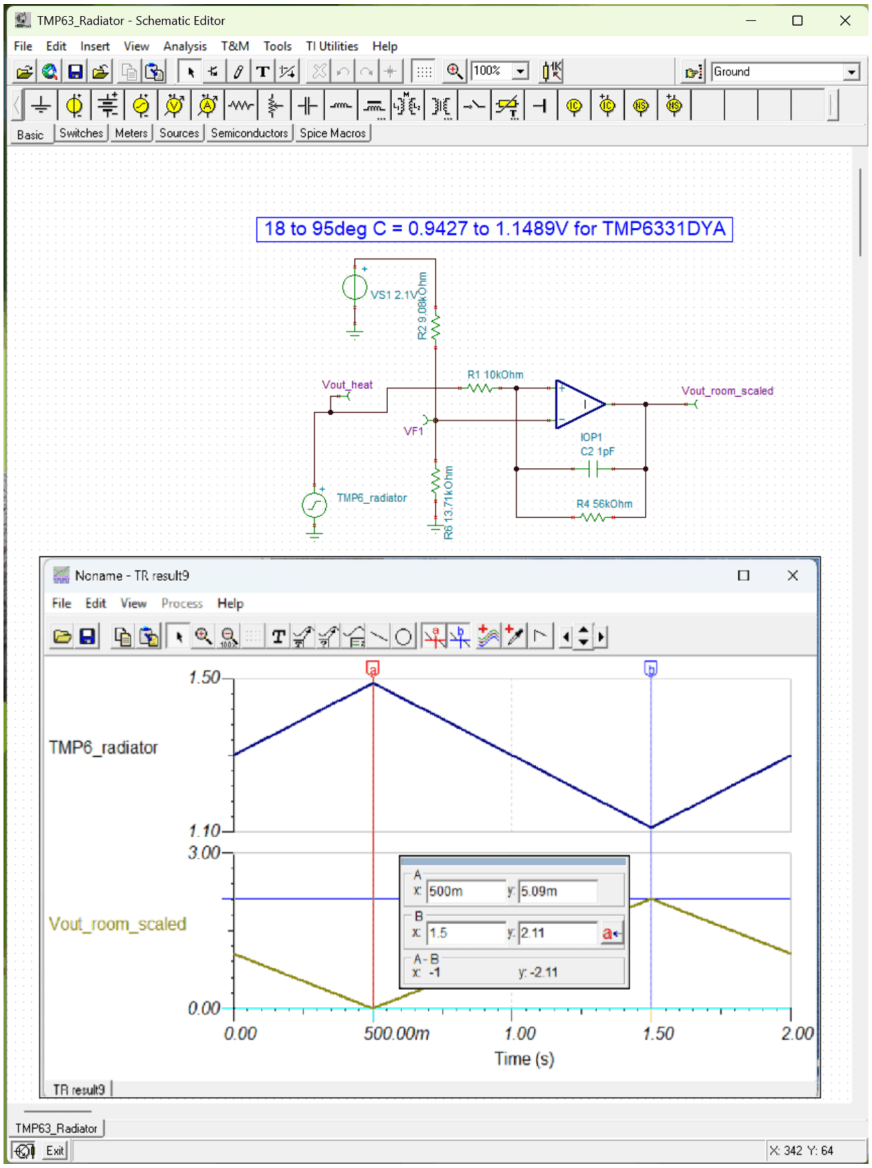

Figure 5-2. TMP63 Heater Sensor Circuit With Simulation

The 2.1V supply were chosen, as the end-of-life voltage at the end of lifetime of a 3V LiMnO2 primary cell, which are commonly used in Heat Cost Allocators. The ADC12 module can use VDDS as the reference voltage and thus utilize tthe range of 0V to 2.1V as the full ADC scale, even when VDDS drops over lifetime from 3.25V (new cell) down to 2.1V (representing an empty battery cell).

The signals on TIDA-00848 PCB available for temperature sensing are:

- DIO_28 = Vtmps_1
- DIO_27 = Isrc_1 (analog output to the first TMP63 sensor) - in this design re-purposed as BASE_PWM_N signal to drive the LCD
- DIO_29 = Iscr_2 (analog output to the second TMP63 sensor)

The temperature sensing code has not been implemented and tested yet. The code can be written for the main M4F MCU core, as typically temperature is measured 1-2 times per minute and power penalty is low, especially if combined with other periodic application code functions. Alternatively, the SCE module can be used for converting the ADC12 codes into temperature values, as existing SCE RAM usage with both touch and LCD tasks is 35.7% or 731 words (16-bit long) and leaves plenty of RAM free for temperature code calculations. If the SCE is used for this code, then careful alignment of task timings is mandatory, as LCD frame timing must have the highest priority; where the other tasks must be scheduled in between the LCD frame activity.

5.2 Capacitive Touch Area on the PCB

The TIDA-00848 PCB integrates a round PCB area next to the SMA antenna connector for detecting a touch event, based on capacitive sensing approach. The sensor controller firmware example project supports two concurrent tasks, as seen in Figure 5-3. First task checks the PCB capacitive touch area every second (this period is also software configurable by the user). The second task utilizes the SCS LCD resource and generates properly timed waveforms for the LCD MUX TI patented design.

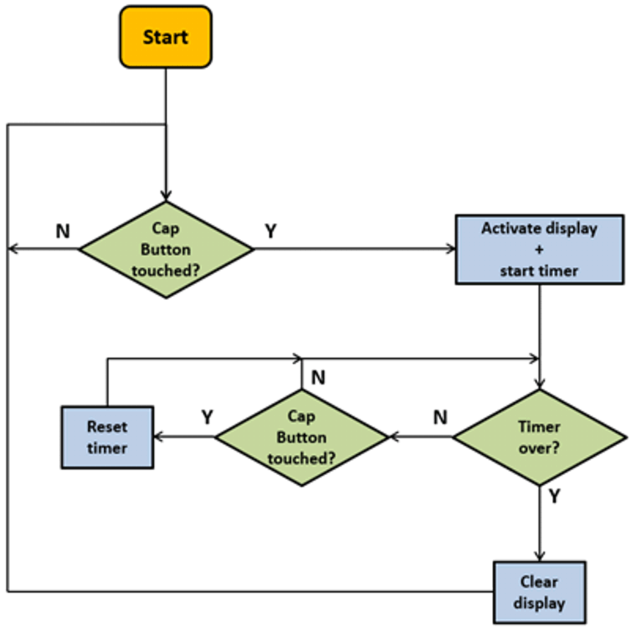

Figure 5-3. Flow Chart of SCE Firmware for LCD Activation With CapTouch

5.3 Battery Power

The TIDA-00848 has been developed with the goal of supporting both primary cell voltages of 3.0 V ($LiMnO_2$) and 3.6 V ($LiSOCl_2$). These chemistries have significant differences in their behavior, especially under pulse load and ambient temperature. In general, the addition of a buffer capacitor aftin parallel to the battery can help absorb the peak current during RF transmission; here, a Würth device WCAP-ATLI with 1200 µF / 10 V has been selected.

If 3.0V batteries from type FDK CR14250SE or the higher capacity FDK CR½ 6LHT are used, then it is possible to reduce or even completely remove the buffer capacitor of 1200µF as these batteries can sustain the periodic peak current of 20mA for 10ms without lifetime degradation. To properly dimension the buffer capacitor, contact the selected battery manufacturer and provide the current profile of the application as precisely as possible.

6 Getting Started Firmware

A full version of the TI CCS Version 12.8.1 (Eclipse based) or CCS20.5 (Theia) together with the TI RTOS installation included in the TI SIMPLELINK-LOWPOWER-F2-SDK version 8.32.00.07 or later is required to compile and debug the TIDA-00848 firmware.

To ease developing the program code running on the SCE module, TI provides a complete tool chain for writing software for the controller: Sensor Controller Studio (SCS) 2.0.9.208.

This is a fully integrated tool consisting of an IDE, compiler, assembler, and linker which generates the SCE binary code. The complete firmware code project combines application code for the CC1312R with the SCE code into a single source code deliverable (TIDA-00848_firmware.zip).

The provided CCS source code project includes a SCS sub-project, found in the install path / HCA-848_CC1312R1_TouchLCDon/sce_output and named "HCA-00848_CapTouch_LCDon.scp".

6.1 SCS Code Project

Two tasks have been defined: one for the touch event and the other one for the driving the LCD display BTL002.

6.1.1 SCS Task CapTouchButton

The CapTouchButton task uses the COMPA, the TDC, and the ISRC blocks to implement the "CapTouch" event detection. The dedicated PCB area (small circular copper pad) is connected to COMPA input through the DIO_30, while the COMPA reference is the DCOUPL signal, which is nominally at 1.27V. The TDC counts the time ticks (in 96 MHz ticks) needed to charge the PCB area (which represents a capacitor between top and bottom layers) to 1.27V, such that the COMPA changes the output to high.

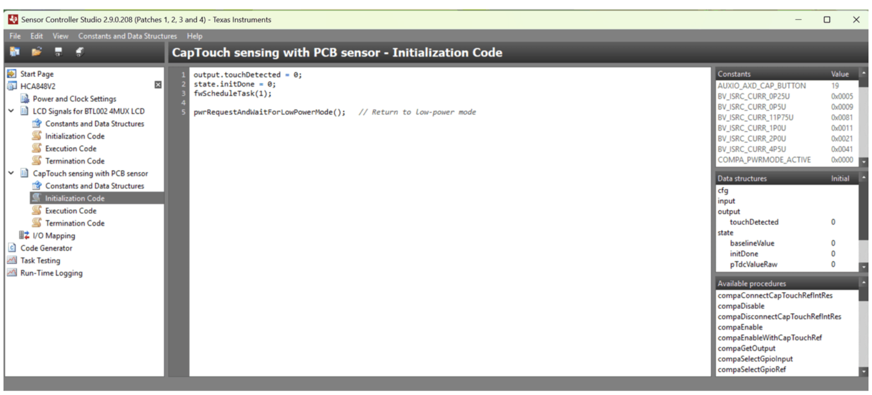

Figure 6-1. SCS Project for CC1312R: CapTouchButton Task (Initialization Code Portion)

The execution code portion for the task is shown in Figure 6-2:

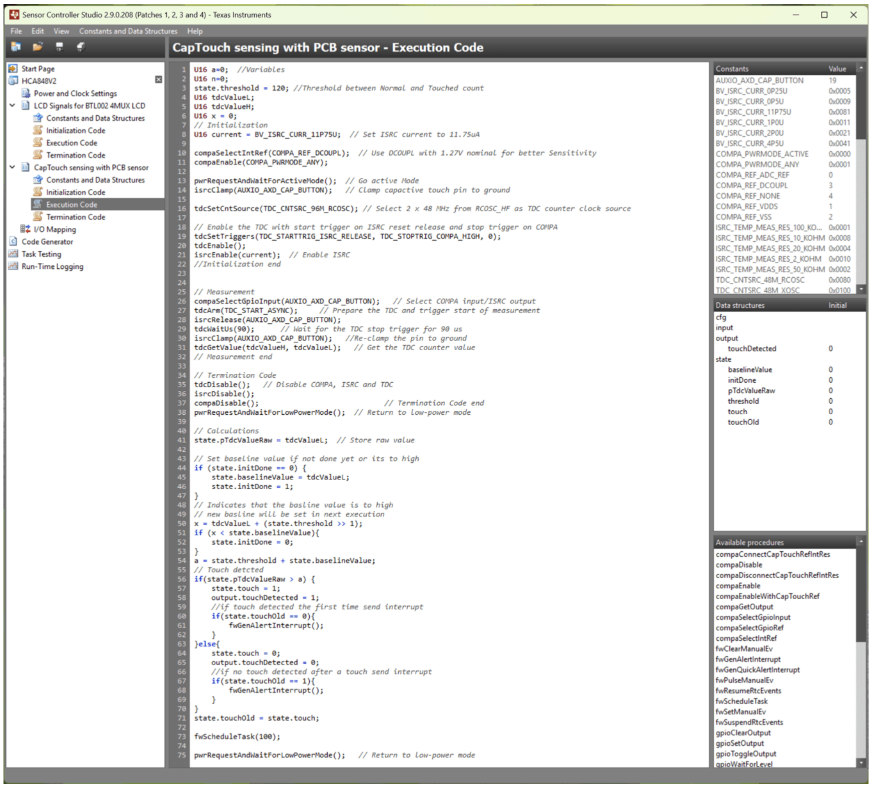

Figure 6-2. SCS Project for CC1312R: CapTouchButton Task (Execution Code Portion)

The variable "threshold" sets the difference between non-touch and touch events (if necessary, the value of 120 can be adjusted). If such result has been detected once, then immediately a second measurement cycle of 90µs is started to confirm that this is indeed a touch event (and not just an external noise).

If both measurements deliver a delta value above the threshold, then an interrupt to the Cortex-M4F core is raised using the fwGenAlertInterrupt() function. The CapTouchTask is rescheduled to run in one 1 RTOS tick later, where the RTOS tick has been set to 1 second.

6.1.2 SCS Task LCD

The task named *LCD Signals* in the *HCA-00848_CapTouch_LCDon.scp* file maps the 27 DIO lines as per TIDA-00848 schematics to the BTL002 pins.

The task contain Initialization, Execution and Termination code sections where multiple LCD resource function calls like lcdInit(), lcdPrepareNextState() and lcdApplyNextState() are utilized.

6.2 CCS Code Project

The sensor controller code has been integrated inside the /sce_output folder within the TIDA-00848 firmware.

The TIDA-00848 with CC1312R and LCD firmware has been tested for power consumption using the FET430 TI tool with EnergyTrace (tm) functionality.

7 Test Data

The TIDA-00848 hardware is tested in several steps, focusing on three areas:

- Sensor controller tasks (CapTouch event detection)
- LCD with sufficient contrast on multiple segments, for example displaying the string *touched* or *cc1312r*
- Voltage 3.3V to 2.5V (contrast is lower, can be improved by dynamically increasing the frame rate when battery voltage drops over lifetime)

7.1 Sensor Controller Task for CapTouch Detection

The *pattern detected* variable at the bottom graph is representing the touch event; the output.pTdcValueRaw and output.pTdcValueFilt show the number of 96MHz ticks measured (Raw) and after some simple filtering (Filt).

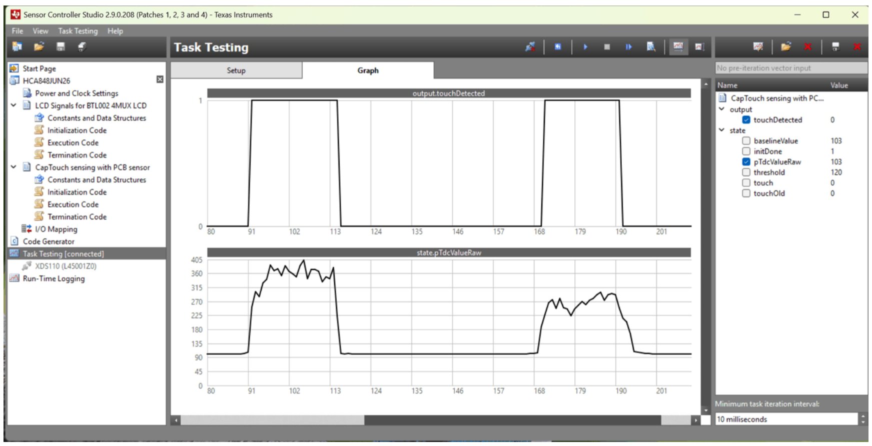

Figure 7-1. Task Testing Under SCS: Touch Events are the Peaks in the Two Upper Graphs

7.2 LCD

Two different values for the inverted BASE_PWM_N line and the serial resistors for the segment lines have been tested: R1 through R4, R7 through R10, R13 through R17, R19 through R22, R5 through R27, with either 3MΩ and 10MΩ. The final decision was to keep the 10MΩ value as this delivered lower average current while the LCD contrast did not change visibly.

Also the R28 with 11kΩ and R29 with 22kΩ in Rev1, have been increased to 100kΩ and 200kΩ, and later to 1MΩ and 2MΩ to better fit the 3MΩ or 10MΩ serial resistors for the SEG lines.

7.3 TIDA-00848 Current Consumption

The power consumption of the TIDA-00848 was measured with the TI FET430 tool with EnergyTrace technology.

SEG_BASE_COMMON [R1-4, R7-10, R13-R22, R25-27]	COM1-4 [R30, R32, R34 and R36	COM1-4 [R31, R33, R35 and R37]	TIDA-00848 Power consumption [LCD on, 3V supply]
3MΩ	100kΩ	200kΩ	128.3 uA
3MΩ	1MΩ	2MΩ	11.8 uA

8 Design Files

8.1 Schematics

To download the schematics, see the design files at TIDA-00848.

8.2 Bill of Materials

To download the bill of materials (BOM), see the design files at TIDA-00848.

8.3 PCB Layout Recommendations

The TIDA-00848 is a two-layer PCB with approximately 1mm overall thickness; the two layers are for the lowest cost while the 1mm thickness increases the mechanical stability of the PCB. The layout has been modified on the top layer copper to achieve 50Ω strip-line impedance of the RF line to the SMA antenna connector.

8.3.1 Layout Prints

To download the layer plots, see the design files at TIDA-00848.

8.4 Altium Project

To download the Altium project files, see the design files at TIDA-00848.

8.5 Gerber Files

To download the Gerber files, see the design files at TIDA-00848.

8.6 Assembly Drawings

To download the assembly drawings, see the design files at TIDA-00848.

9 Software Files

To download the software files, see the design files at TIDA-00848.

10 References

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12 Terminology

Heat Cost Allocators (HCAs)	Battery-powered electronic devices, used to capture the proportionate thermal output of radiators in consumer units
Heater sensor	Temperature sensor, attached to the radiator (or heating element)
Room sensor	Temperature sensor for monitoring the room or ambient air temperature
wM-Bus	The European RF metering standard, providing solutions for the 169-, 433-, and 868MHz bands
LCD	Liquid crystal display

13 About the Author

MILEN STEFANOV (M.Sc.E.E) is a system engineer at TI, working in the field of Grid Infrastructure and an expert in RF communication technologies and metering applications. After graduating at the Chemnitz University of Technology (TUC), he worked there for 5 years as a research assistant. Later he was a system engineer for 3.5 years in the semiconductor industry in high-speed optical and wired communications before joining TI in 2003 to become a Wi-Fi expert and support TI's Wi-Fi products at major OEMs.

Since 2010, he is focusing on metering, sub-metering and sub-1GHz RF solutions for the European Grid Infrastructure market. Mr. Stefanov has published multiple articles on wM-Bus technology in Europe and presented technical papers at the Wireless Congress and Smart Home & Metering summits in Munich.

The author would like to give special recognition to **PETER SPEVAK**, former TI MGTS member and group technical staff, for contributing his *SW controlled Segment-LCD using GPIOs* patent and his involvement in the hardware and software design effort for the TIDA-00848.

ANDREAS LECHNER (M.Sc.E.E) is a system engineer in the Energy Infrastructure team at Texas Instruments, focusing on power conversion and renewable energy. He received his master's degree in electrical engineering at the University for Applied Sciences, Landshut.

14 Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Revision A (June 2016) to Revision B (July 2026)	Page
• Updated the numbering format for tables, figures, and cross-references throughout the document	1
• Updated SW example with LCD support in the SCE module	3
• Added simulation files for dual temperature sensors TMP63	15
• Updated SCH, BOM, and Altium CAD project with CC1312R	21

Changes from Revision * (June 2016) to Revision A (June 2016)	Page
• Changed from preview page	1

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